Design of a prototype for teaching general relativity to upper secondary students

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1. Introduction

General relativity is one of the major modern theories in contemporary physics together with quantum physics. General relativity is not part of the standard upper secondary school physics curriculum in the Netherlands. The goal of our design based research project is to develop and evaluate curriculum materials on general relativity for upper secondary physics classes. The research question is: “What does a design of a prototype for teaching general relativity to upper secondary students in the Netherlands look like?”

2. Development of design principles

- Literature review
  Different levels that GR is taught at Challenges when teaching GR at lower levels
- Textbook analysis (N=9)
  Math-first --- physics first [1,2]
  Compared visuals, exercises, worked examples and topics
- Expert rounds
  Round 1: content knowledge expert
  Round 2: didactic knowledge experts (N=26)
- First trial run (upper secondary students, N=28)
  Total of 6 lessons (50 minutes each)
  Questionnaire and student interviews

3. Design principles

<table>
<thead>
<tr>
<th>Design principles</th>
<th>Rationale</th>
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<tbody>
<tr>
<td>1. The module 'general relativity for upper secondary pre-academic students' contains interesting contexts.</td>
<td>- Interesting contexts foster student engagement.</td>
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<td>2. The level mathematics within the module should be close to the level of mathematics that can reasonably be expected of an upper secondary pre-academic student.</td>
<td>- A 'math-first' approach is not feasible for upper secondary pre-academic students. - The exercises should approximately be of the same level as the national mathematics exams.</td>
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<td>3. Curriculum materials should be presented in an age-appropriate way.</td>
<td>- The student should be able to comprehend the curriculum materials. - The exercises should approximately be of the same level as the national physics exams.</td>
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<td>4. There is enough visual support in the curriculum materials.</td>
<td>- Visuals, such as pictures, animated images and video’s, enable students to grasp abstract concepts</td>
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<td>5. The module contains hands-on experiences like exercises, worked examples and student-activities.</td>
<td>- The engagement of the students is increased which stimulates learning.</td>
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<td>6. The module also enables students to study the materials independently from the teacher.</td>
<td>- Instructional scaffolding helps students achieve a high-level understanding of general relativity.</td>
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<td>7. The module should be embedded within the current physics curriculum.</td>
<td>- This decreases the amount of time spent on 'extra-curricular' activities, therefore it will better fit within the time-constraints that teachers and students experience in upper secondary classes in the Netherlands.</td>
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<td>8. The module is appealing and encourages the student to read and study the curriculum materials.</td>
<td>- The structure and layout of the materials is clear for the students and encourages learning.</td>
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<td>9. The structure of the module is consistent and coherent.</td>
<td>- Each chapter of the textbook are parts of a whole. Each following chapter is a logic continuation of the previous chapter.</td>
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- The explanations have to be specifically aimed at the students’ skill and comprehension levels.
- The use of (hands-on) models [3] and visualization techniques can further aid in helping students wrap their heads around the various abstract concepts.
- Student motivation increases if the module is well embedded within the current curriculum.
- Module is designed around four key concepts based on similar key concepts identified by other authors [1,4].